DOCUMENTS EXPEDITING PROJECT

THE GROUND-CUSHION PHENOMENON

REPORT

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., May 26, 1959.

Hon. OVERTON BROOKS,
Chairman, Committee on Science and Astronautics.

DEAR MR. CHAIRMAN: I am forwarding herewith for committee consideration a report on "The Ground-Cushion Phenomenon," prepared by staff consultant Lt. Col. Paul B. Schuppener.

This report is based on releasable portions of testimony provided by knowledgeable witnesses representing the military departments and industry, and on information gathered from other qualified sources. It discusses the ground-cushion phenomenon itself and applications to vehicles having great potential value to military operations and to the civilian transportation industry. Certain of the applications will require a relatively small additional development effort while others, although showing considerable promise, will require not only continued applied research but a significant amount of development work.

CHARLES F. DUCANDER,
Executive Director and Chief Counsel.

LETTER OF TRANSMITTAL

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THE GROUND-CUSHION PHENOMENON

I. INTRODUCTION

Kipling has said, "Transportation is civilization." The truth of these words is evident from the rapidity with which civilization has advanced under the impetus of inventions providing new means of transportation.

In the Paleolithic age there were no aids to transportation; the stone-age man walked, and if he came to a river he swam or paddled himself across on a tree trunk. In the Neolithic age he learned to make a sledge on which to drag home his freshly killed game, and he found that with fire and sharp-edged stones he could form a tree trunk into a dugout canoe. Much later, about 3000 B.C., there is evidence to indicate the invention of the wheel by the people of southern or eastern Asia. The invention of the wheel opened new vistas of trade and commerce and sped the exchange of knowledge between peoples.

Waterborne transportation gained new importance from the appearance of square-rigged sails on Egyptian vessels just before 3000 B.C. The introduction of the lateen or triangular sail by the Arabs about 600 A.D. made possible the sailing of vessels on crosswind courses and led ultimately to the design of the ships of Columbus and Captain Cook.

During the past 200 years economic progress and the spread of cultural knowledge have been particularly great. These advances can be attributed directly to a whole series of inventions within that period—the steamboat, the steam carriage (forerunner of the modern automobile), the steam locomotive, the gasoline motor-driven automobile and the first power-driven airplane, which flew successfully in 1903.

Each invention or improvement of transport vehicles has been based upon at least one of two important considerations—the harnessing of a new or previously inaccessible source of power with which to drive the vehicle, or an increase in the ease of movement through the reduction of friction. Now it appears that we may be entering an early phase of development based on a discovery which materially reduces the wasteful, retarding force of friction by allowing vehicles to roll on a cushion of air over land, sea, swamp, sand, or snow. The ground-cushion phenomenon, as it is known, if successfully harnessed, can have its important effect on the advancement of our civilization.

The Committee on Science and Astronautics, realizing the potential importance of such a development, determined to ascertain its status and possible future applications. Knowledgeable witnesses from industry and the military services were invited to testify before the full committee. Included were John B. Macauley, Deputy Director of Defense Research and Engineering, Department of Defense; Rear Adm. Rawson Bennett, Chief of Naval Research, Department of the Navy; Brig. Gen. Frank H. Britton, Director of Developments, Office,

Chief of Research and Development, Department of the Army; Dr. Andrew A. Kucher, vice president, engineering and research, Ford Motor Co.; Mr. Carl W. Bollum, Sr., president, Spacetronics, Inc.; Mr. William H. Alper, president, National Research Associates, Inc.

Certain of the Army and Air Force work in this field is carried under a military security classification and was disclosed to the committee in closed session. Only those portions deemed releasable have been referred to in this report. Information received during the course of open hearings and gathered separately from military, industry, and scientific sources are summarized herein.

II. THE GROUND-CUSHION PHENOMENON

Conventional airplanes and helicopters depend almost exclusively on aerodynamic lift produced by the rapid movement of properly shaped airfoils (wings or rotors) through the air. However, during landing or takeoff such aircraft do experience substantial effect attributable to the ground-cushion phenomenon. This transitional effect can be used to augment the lifting capacity of an airplane or helicopter by as much as 10 to 20 percent for operations a few feet from the ground. In fact, the hovering ceilings both "in" and "out" of ground-cushion effect have become design parameters of rotary-wing aircraft.

Recognition of the ground-cushion phenomenon as a primary means for support of a vehicle in the air led to the beginning of research in Europe in the late 1930's. In this country Dr. Andrew A. Kucher proposed more than 30 years ago, in 1928, the concept of a wheelless vehicle that would ride on a thin film of air a fraction of an inch above the roadbed. Work by individual investigators, and at least one major aircraft company, continued in a desultory fashion in the 1940's. The first known experimental work performed by the U.S. Government having significance for possible application to vehicles was by the National Advisory Committee for Aeronautics' Lewis Laboratory, beginning in June 1954. Results of the Lewis Laboratory experimental work were published in April 1957 in a report entitled "Exploratory Study of Ground Proximity Effects on Thrust of Annular and Circular Nozzles."

It should be noted, however, that work on one specialized application of the air-cushion phenomenon was begun for the Army by a group of German missile scientists headed by Dr. Wernher von Braun shortly after their arrival in this country in the fall of 1945. In this case, the application was most specific to the design of near-frictionless air bearings to reduce the drift or precession of gyroscopes used in ballistic missile guidance systems.

With the exception of this specialized missile application, interest of the U.S. Government stems mainly from the effects demonstrated by the Lewis Laboratory. The Lewis Laboratory showed experimentally, through use of an annular jet nozzle, that when high pressure air was discharged from the periphery of the nozzle there was an unexplained increase in reaction or lifting force on the nozzle if the exit was less than one and a half nozzle diameters from a rigid surface. This increased lift is in direct contrast to the effect experienced if the air is discharged from an unrestricted nozzle. In the latter case the thrust is actually reduced as a result of the reaction of the airstream with the ground.

The so-called ground-cushion phenomenon is attributable to certain characteristics of air. These characteristics, compressibility and viscosity, or resistance to flow, are well known to aerodynamicists and airplane design engineers. Air, forced between the bottom of a machine or vehicle and a rigid surface such as the ground, asserts its inherent resistance to compression by exerting equal and opposite pressure against the ground and the device. The upward pressure of the air on the machine, multiplied by the area against which it acts, becomes the lifting force which floats the machine on a cushion of air. Of course, lacking a seal at the edges, air escapes, but here another characteristic of air becomes important. The viscosity or internal frictional force manifested when the air begins to flow out at the edges acts to retard or limit the escape of air and to preserve a relatively stagnant region of air at the center. This appears to be an essential condition to the establishment of the air cushion. The system soon attains equilibrium, in which the machine floats at a height above the ground dictated by the rate of flow of air pumped into the space between the ground and the machine, the combined weight and load of the machine and the area of the bottom of the machine. There are other influencing factors, but these are fundamental.

Force to propel the machine is a separate problem but, because the machine can now roll on an almost frictionless cushion of air over land or water, the power requirements are considerably reduced to produce what otherwise would be considered high ground speeds and extremely high water speeds. Power to propel the machine can be provided by the conventional engine or gas turbine driving a propeller, by jet engine, or by air jet. Operating heights of vehicles varying from a fraction of an inch to perhaps 50 feet appear feasible. Vehicle speeds of more than 100 miles per hour over land, water, marsh or snow are contemplated.

The manner in which the ground cushion is maintained varies considerably with the intended use. For example, in the air-bearing application illustrated in figure 1, air escapes radially, with no attempted restraint. The height of lift is therefore rather strictly limited and the operating surface must be smooth. The use of a plenum chamber as shown in figure 2 may add somewhat to the height of lift and permit traverse of water and more irregularly formed ground. The addition of an annular jet, as illustrated in figure 3, has at least one important effect in that it forms a curtain of relatively high velocity air, directed at the ground, which tends to restrict the radial escape of air to a much greater extent than does the plenum chamber. Still another proposal utilizes a so-called labyrinth seal. In this application there are a number of discontinuous annular chambers arranged so that air is ejected as a series of oblique jets at different radii on the base of the vehicle. In this manner most of the air ejected downward is recaptured by the stages operating at greater radii from the center. The advantage of this type is possibly greater power economy.

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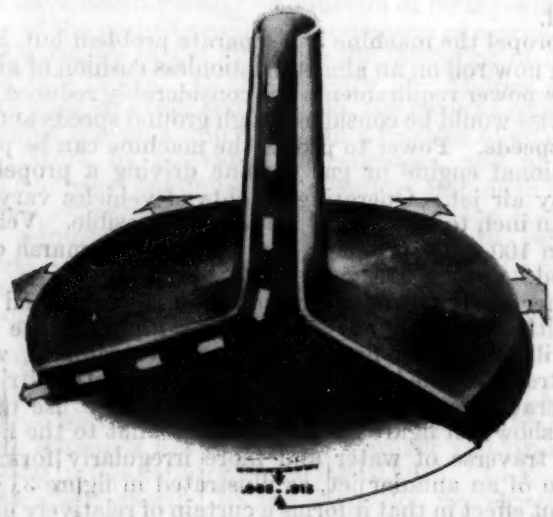

FIGURE 1.

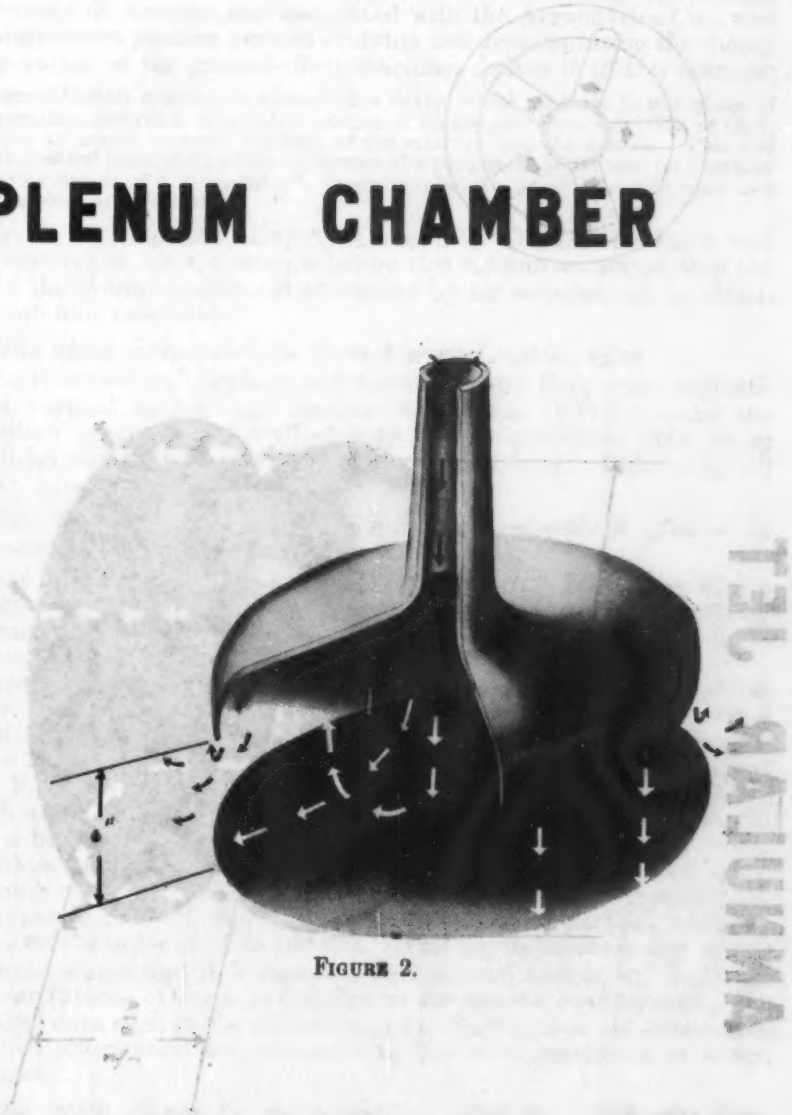

FIGURE 2.

FIGURE 3.

III. GROUND-EFFECT MACHINES

Machines or vehicles which make use of the ground-cushion phenomenon have been called ground-effect machines, ground proximity machines, minimum ground pressure vehicles and by various trade names. Dr. Gabriel D. Boehler, member of the faculty of Catholic University of America and associated with the Aerophysics Co., who has done much pioneer work in evolving and demonstrating the theory of operation of the ground-effect machine, defines it in this manner:

> A ground-effect machine is defined as a device which, at least in one phase of its operation, derives a substantial portion of its support from a cushion of high-pressure air sealed between the base of the machine and the ground. This seal can be realized practically either by means of a peripheral high-speed jet (annular jet) or by means of a "labyrinth." Operationally, the machine can be used as a truck, a ship, or an airplane.

Mr. J. B. Macauley, Deputy Director of Defense Research and Engineering, in his appearance before this committee stated that the use of the ground-cushion phenomenon by air vehicles can be classified into four categories:

Vehicles which make transition through ground-cushion effect

The conventional airplane and helicopter and their more sophisticated vertical takeoff and landing derivatives (VTOL) make the transition through ground effect very rapidly and make little or no beneficial use of the ground-cushion phenomenon. Practically all known flying machines fall in this category.

Vehicles which operate effectively either by ground-cushion effect or by aerodynamic lift

Next is the aerial-vehicle type of VTOL aircraft. It operates within the ground cushion as a vehicle riding on air, but after obtaining minimum velocity functions as an aircraft and is supported by aerodynamic forces generated by its forward motion.

There is a joint Army-Air Force sponsored program carried on under contract with Avro Aircraft, Ltd., of Canada, to develop a VTOL research vehicle of this nature. The research vehicle, known as the Avrocar, has been identified as a disk-shaped vehicle by Brig. Gen. F. H. Britton, Director of Developments, Office, Chief of Research and Development, who testified as an Army witness. It will have a hovering capability, as do other ground-effect vehicles, but it will have high performance outside the ground cushion, and after attaining minimum velocity will function as an aircraft supported by aerodynamic lift. It was stated that the desired operating altitude will be on the order of 50 to 100 feet. This development is now in the advanced stages and it is expected that ground testing will begin in the near future. Details pertaining to the specific configuration and technical data such as the method of controlling airflow are considered classified information not releasable at this time, according to Army witnesses.

Vehicles which operate by ground-cushion effect and which may have limited conventional surface mobility

A third type of vehicle, categorized by the Department of Defense, is sometimes called a minimum ground-pressure vehicle. It operates at all times within the ground cushion over open land or sea areas.

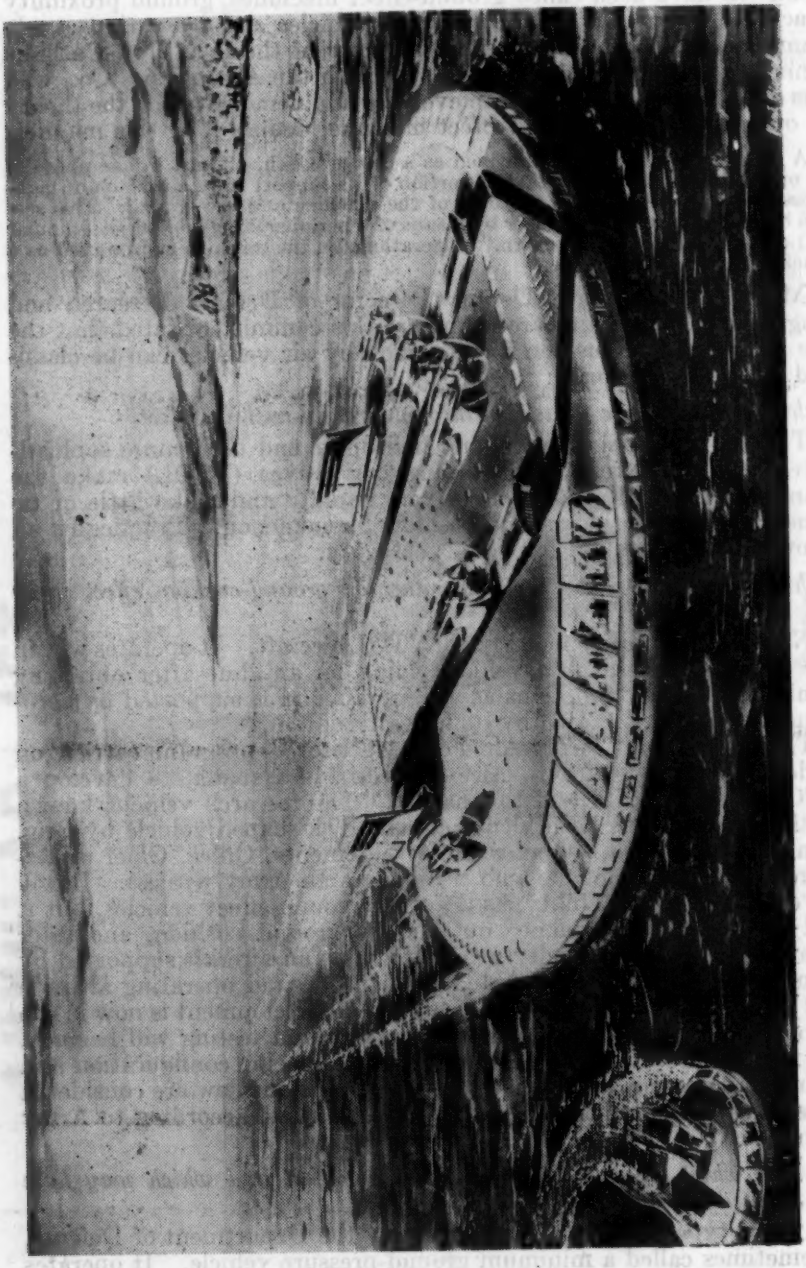

FIGURE 4.

The movement of this vehicle is not restricted by mud, snow, ice, or other similar surface obstacles which impede the movement of wheeled vehicles.

The Navy has a number of relatively small contracts designed to further their interest in applications such as an amphibious transport or assault boat. These devices would travel 4 or 5 feet above the wave tops at speeds up to 50 miles an hour and be capable of negotiating beaches up to 15 percent slope. The Navy also has in mind the possibility of a radio-controlled antisubmarine warfare platform. It would operate at heights only great enough to clear the waves and at speeds up to 20 percent greater than the latest atomic submarine. More advanced thinking, insofar as naval use is concerned, involves a circular shaped platform up to 1,000 feet in diameter and capable of speeds up to 150 knots (fig. 4). Because of the large size such a machine might operate up to 50 feet above the waves, thus permitting maximum weight lifting potential and stability.

Several research vehicles under development by private concerns also fall into this category. Spacetronics, Inc., has its Hydro-Air vehicle, which makes use of an open plenum chamber on the under side, into which air is pumped and allowed to leak from around the bottom of the vehicle. Mr. Carl Bollum, president of Spacetronics, Inc., states that—

> We have discovered that the Hydro-Air vehicle is stable in attitude in heights above the surface of the earth up to one-tenth of its equivalent diameter and no controls are required, other than steering and throttle controls for the thrust and the air pump motor. Further development and tests will be required before the upper limits in altitude without attitude controls can be determined.

Mr. William Alper, president of National Research Associates, Inc., stated that his company has an Army contract for a feasibility study of a minimum ground-pressure vehicle which incorporates the free-air suspension system. He stated that—

> This type of vehicle employs a peripheral jet which generates and contains pressure underneath the vehicle to provide it with support. In other words, this vehicle rides on a cushion of air which is contained by an air wall.

He pointed out that the free-air suspension system vehicle will also be equipped with wheels and a lightweight suspension system in order that it may be driven in and out of buildings and along city streets and highways.

Spacetronics, Inc., and National Research Associates, Inc., are small concerns engaged in experimental work on ground-effect machines under very limited budgets. Both, with little or no funds from outside sources, have built experimental vehicles for feasibility demonstrations.

Vehicles which operate on a very thin film of air over a smooth surface

A fourth application of the ground-cushion phenomenon is represented by a vehicle that operates on the air-bearing concept, which is that friction with surface terrain is significantly reduced by a thin film of air between the surfaces of the vehicle and the support (fig. 5).

Dr. Andrew A. Kucher, vice president, engineering and research, Ford Motor Co., testified concerning a Ford development utilizing the airbearing for support. Instead of wheels the Levacar employs levapads. Tiny jets of air stream through holes in the levapads supporting the vehicle and permit it to slide at high speeds over a rail,

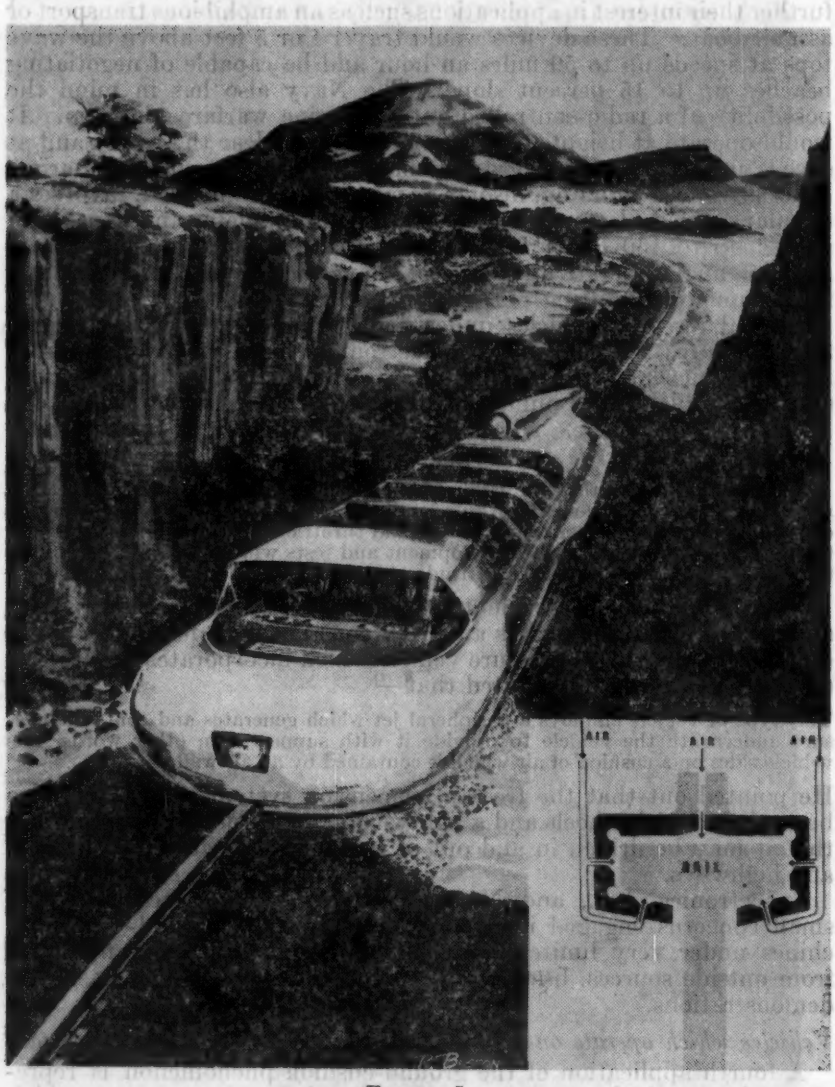

FIGURE 5.

using air as a lubricant. Because there would be no road friction to overcome, full size Levacars would be propelled either by gas turbine engines or turbojets. Engines would also supply the air to levitate the vehicle. Speeds of over 200 miles an hour appear practicable.

IV. FUTURE APPLICATIONS

Civilian and military witnesses were united in expressing interest and optimism for the future uses to which vehicles employing the ground-cushion phenomenon may be put. Certain of the applications appear to be nearer at hand than others. It is obvious that more time and very probably a considerable amount of money will have to be devoted to research and development before some of the possible applications can be fully realized.

The following excerpts, taken from the public statements and testimony of witnesses appearing before the Committee on Science and Astronautics, are representative of current opinion of persons most involved in this field.

Mr. J. B. Macauley

A number of factors have influenced the increase in interest of scientists and engineers in learning more about the ground cushion and its effect on air vehicles, particularly military aircraft.

First, the technological competition between the East and the West has demanded the investigation of any natural phenomena that might improve our military or economic systems.

Second, the increasing realization of the capability of an enemy to use nuclear weapons in any kind of conflict will require dispersal of installations and inhibit concentration of troops; consequently, our Armed Forces must have much greater degree of mobility than ever before.

Third, the possibility that free world forces will have to fight in less developed areas where inadequate transportation systems exist. This factor again indicates the need for increasing the mobility of military forces and reducing their dependence on such prepared facilities as roads, railroads, airfields, and port facilities. * * *

Sporadic investigations have been made during this decade by scientists and engineers for advantageously applying the ground cushion to hardware—all of these were conducted by the trial and error method. The Department of Defense, recognizing the military potential of ground-effect machines, is now coordinating the research and development activities of the services to provide an understanding of the ground-cushion phenomenon. In this manner, the Department of Defense can arrive at timely decisions to proceed with prototype developments that will result in significant increases in the combat effectiveness of the Armed Forces.

Brig. Gen. Frank H. Britton

Military success depends upon firepower, communications, and mobility. You are thoroughly familiar with the tremendous advances that have been made in firepower available to military forces since World War II. Similarly, communications have been vitally improved. For our Army to exploit these advances both offensively and defensively, mobility must keep pace, but improvements have lagged behind the achievements in the two other fields. The American Army has made and is making definite advances in ground mobility, but something more is required for the future—particularly in limited war. We hope to provide much of the mobility required in the future by the integration of air vehicles into combat and combat support units. Originally, Army aviation was used principally for observation, command, and liaison-type missions. Since World War II its capabilities have been exploited and expanded for additional missions such as the movement of troops in the combat zone, the movement of critical supplies, and battlefield casualty evacuation. We are now moving toward the use of aerial vehicles as actual replacements for ground vehicles in certain combat units. First to be considered are those units fulfilling the traditional cavalry roles of reconnaissance, screening, pursuit, and other such tasks requiring "hypermobility" in comparison with the rest of the Army.

For centuries the armies of the world have used woods, hills, and other terrain features to provide cover and concealment. On the other hand, these very same features have seriously limited these armies in their mobility and maneuverability. With air vehicles designed for our purpose, we expect to develop certain air-mobile units which will continue to make use of terrain features for cover and concealment, yet free these same units from obstacles of terrain. * * *

I make reference to the joint Army-Air Force-sponsored program to develop a VTOL research vehicle with AVRO Aircraft, Ltd., of Canada, which makes use of the ground-cushion phenomenon. This research vehicle, known as the Avrocar, appears to offer a great potential to the U.S. Army for increasing its mobility in the combat area.

Rear Adm. Rawson Bennett

Preliminary results of initial research efforts have indicated that the ground proximity machine will be able to operate with equal facility over land and water. Therefore, one of the more obvious uses for such a machine is as an amphibious transport or as an assault boat. A boat-type bow and watertight structure with low silhouette and moderate load-lifting capability are design criteria dictated by this mission. Vehicles comparable in size and payload to present amphibious assault craft would be extremely valuable in accelerating the ship-to-shore movement. Traveling 4 or 5 feet over the wave tops at speeds up to 50 miles per hour and capable of negotiating beaches up to 15-percent slope, the vehicle would present a far less vulnerable target than our present craft and would open the world's tideland and river delta areas as avenues of approach for assault or for peaceful cargo moving.

An application to antisubmarine warfare is visualized using searching and homing devices mounted on a radio-controlled platform. This hunter-killer platform would have to operate at heights only great enough to clear the waves and at speeds only 20 percent higher than the latest atomic submarine. Structurally, the platform should be capable of floating in heavy seas for extended times—then lifting and tracking automatically. Because of its inherent weight-lifting ability, the machine becomes an ideal killer—able to place a bomb or charge directly on the enemy submarine by radio command from the mother ship and then scoot away to safety. * * *

Circular ship platforms 1,000 feet in diameter, capable of speeds up to 150 knots, have been outlined in foreign newspapers and periodicals. Because of their huge size, these machines might operate up to 50 feet above the waves, thus permitting maximum weight-lifting potential and stability.

These are by no means the only ones possible. Our investigators are studying these and many others, and it is certainly possible that some use not even contemplated at this time may be the most worthwhile adaptation of the ground proximity principle. * * *

Since our first investigative efforts, the Navy has exhibited leadership and maintained an overall cognizance of the work being done. It is our intention to continue to "look forward" through an objective program which will accomplish the required phases of research and exploratory development leading to the acquisition of an optimum vehicle.

Dr. Andrew A. Kucher

We look upon the Levacar as a new form of high-speed land transportation, probably in the field of rail surface travel, for fast trips of distances of up to about 1,000 miles. Levapads already have been designed to fit around a rail, not only raising the vehicle from it but also holding it away from the rail sides. The overhead monorail principle is ideally suited to the Levacar. * * *

Gliding on a film of air offers great advantages over flying some distance off the ground in the conventional manner. About 60 percent of a plane's drag is in the wings and empennage. Eliminating these, as we have done in the Levacar, gives considerably greater propulsion efficiency. I foresee that a 250-mile trip in a Levacar, about the distance from Washington to New York, would require less than 1 hour. * * *

We are also analyzing the other systems of air levitation, those which provide a vertical ascension in the same sense as previously described by Mr. Macauley. Our studies again relate to flyable vehicles rather than winged cars. The concept of an automobile with wings has been propagated for years and years. This is untenable. The concept, however, of a flying automobile is not untenable, for the problems of increasing the available power-to-weight ratio and the further ability of instantaneous sensing of forces for corrective action are bordering upon accomplishment. Therefore, it seems to us the combination of those two funda-

mentals can be developed to provide a true "flying automobile." The near-ground movement of small vehicles is the first phase we are pursuing from the study standpoint.

Mr. Carl W. Bollum, Sr.

Among the many potential civilian uses for such vehicles, perhaps the most readily apparent is its use as a sport vehicle which could be used by fishermen, hunters, or merely as a vehicle to replace the outboard motor or speedboat. Commercially such vehicles could be used for transporting personnel and material to and from oil drilling rigs in the Gulf of Mexico, small islands off the coast, and the Texas Towers off Cape Cod. Vehicles could be built which would be able to transport fish from the fishing fleets very rapidly to the market areas and transport men and supplies out to the fleet, enabling the fleet to stay in the fishing area for longer periods of time. For future transportation it is very possible that within a period of 5 or 6 years we may have ferry systems operating from Florida to South America via the islands, carrying automobiles, passengers, and cargo at speeds up to 100 miles an hour. It is also very possible that within the next 10 years a transoceanic vehicle will be built approximately 300 feet in diameter, operating up to 30 feet over the top of the water, at speeds of 200 miles an hour.

Mr. William H. Alper

Forecasting the potentialities of free air suspension system, or peripheral-jet vehicles, depends on a full understanding of the concept and an uninhibited view of, the operating functions which it can perform. For combat vehicles it will provide extremely high mobility since it can operate over a wide variety of terrain and surface conditions. Using its wheels it can be driven in and out of buildings and along city streets and highways but, in addition, when there are no paved surfaces it can lift itself off the ground and traverse terrain surfaces such as water, ice, snow, mud, desert sands, and arctic tundra. Here we wish to reemphasize that this is a surface vehicle; a high mobility vehicle capable of traveling in close proximity to the ground and capable of clearing most obstructions found on the earth's surface.

Combat vehicles whose mobility characteristics would be greatly enhanced by the employment of the free air suspension system, are considered to include combat reconnaissance and tactical vehicles such as light tanks.

Considering the high mobility capability of this type vehicle other applications to such uses as missile carriers, logistic carriers, assault craft and others come to mind.

V. CONCLUSIONS

The ground-cushion phenomenon is not newly discovered. It has been known and investigated over a period of more than 20 years, but in a desultory fashion. Recently, research effort has been stimulated considerably. Theories have been advanced to account for the phenomenon, and do so at least in part. The results obtained so far in unclassified work, while most encouraging, are largely experimental in nature. It remains to be determined whether present theories are completely valid when applied to the design of large size machines and vehicles.

Department of Defense interest centers primarily around: (1) *Vehicles which operate effectively either by ground-cushion effect or by aerodynamic lift;* and (2) *vehicles which operate by ground-cushion effect and which have limited conventional surface mobility.* In the case of the first, as exemplified by the Avrocar project, the rate of effort and funding seem to be adequate at this time for the accomplishment of development objectives. If full development objectives are met, full-scale application will require greatly augmented funding support.

In the case of vehicles operating wholly within the ground cushion, Government direction to produce a coordinated effort has been lacking. A number of small efforts, meagerly financed and deriving little or no benefit from the work of others, has been the rule. The Depart-

ment of Defense appears to have recognized this deficiency and is now proceeding on the basis of a more coordinated effort.

Several small civilian companies have also recognized the possibilities for utilization of vehicles operating wholly within the ground cushion, but have been limited by lack of personnel, research facilities and operating capital. Their efforts have been primarily in the experimental area and they have not been in a position to engage in extensive work on the development of theory. Even so, their efforts leading to the fabrication of demonstration models are commendable.

Of all the applications which can be freely discussed in this unclassified report, the air-bearing type of vehicle, such as has been proposed by the Ford Motor Co., appears closest to availability. Provided that the need can be shown to exist and funds are available, it appears possible to construct a high-speed monorail system with the knowledge now representing the current state-of-the-art.

The future can be bright indeed for this new means of transportation, for it enters the field at a time when our highways are clogged with truck and bus juggernauts and flooded with pleasure cars. The airways, with greatly expanding traffic, are daily becoming more dangerous. The railroads, while continuing to be efficient transporters of heavy freight, are too slow for our speeded-up tastes. Vehicles operating upon the ground-cushion effect may be an important answer to at least part of our civilian transportation problem.

Military uses range from combat and cargo vehicles operating a few feet above the surface to highly versatile reconnaissance or personnel-carrying vehicles capable of hovering a few feet above the surface or flying high and fast. The traditional foes of mobility—mud, swamp, sand, snow and Arctic tundra—need no longer prevent military operations and naval warfare may be revolutionized through use of high-speed above-water vessels.

The interest and optimism of both civilian and military leaders promise important progress in the near future.

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